HALO DIAGNOSTICS

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Context

- Increasing our understanding of beam halo:
  - Three components:
    1. **Analytical**: fundamental physics, scaling laws
    2. **Simulation**: more realistic, include aspects of diagnostics
    3. **Experiment**: usual challenges and rewards
  - All three required as we push ahead. Diagnostic performance defines success of the latter and therefore affects our entire understanding.

- Diagnostics for different scenarios:
  - Purpose built experiments (LANL LEDA, U of Md, etc…)
  - Dedicated beam studies with user facilities
  - Setup and operation of user facilities

Challenges

- Halo – inherently challenging – dynamic range issue in both simulations and diagnostics
- Challenges to diagnostics developers:
  - Typical spec for profile monitors: 5-10% accuracy in measurement of RMS beam size. Sometimes achieve better, sometimes measurements are not believed even at this level.
  - A typical application: match beam envelope to lattice so that emittance growth and halo development is minimized. Confirmation by measuring beam profile to assure RMS emittance is maintained… also measure halo.
- Measuring halo evolution
  - Ring: implies measurement vs. time, possibly with one station
  - Linac/Transport Line: implies measurement vs. distance; many stations
  - Another challenge: cost.

Definitions

- Need clear definition of Halo
  - Amount of beam beyond certain transverse extent? Deviation from Gaussian in tails?
  - Could vary depending on application
  - Parameterization
  - Will drive diagnostic technique
- Need clear definition of requirements
  - Usual: absolute accuracy, stability, resolution, dynamic range, …
  - Measure relative to peak current density in core? Relative stability between measurements, for parametric scan?
  - During operation (as opposed to beam physics experiments), What is figure of merit for a halo tuning exercise?
  - Is on-line, nondestructive measurement required?

Types of Halo Diagnostics

- What are Halo Diagnostics?
- Pre-workshop discussions suggested an expansive definition resulting in 3 types of halo diagnostics:
  1. Devices that measure contributors to Halo
  2. Devices that directly measure halo and halo evolution
  3. Devices that measure the effects of halo development

- All three are represented in this workshop, with a concentration on the second

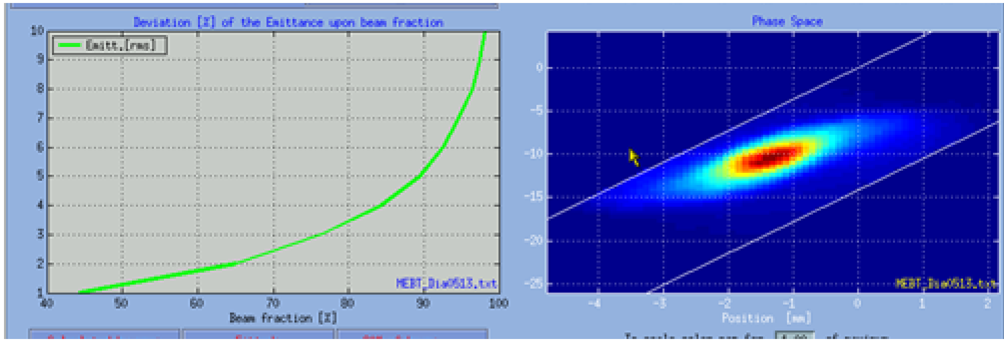
Types of Halo Diagnostics
Some applications and devices

- **Devices to measure contributors to Halo**
  - Standard wire scanners (mismatch)
  - Tune monitors (beam-beam effect)
  - Time resolved profile (variation of space charge along length of bunch)
  - BPMs to measure beamline optics
  - Electron collectors
  - Emittance scanners (initial distribution for simulations)
- **Direct measurement of halo and halo evolution**
  - LANL LEDA profile monitors
  - SNS wires, scraper, IPM, laser
  - HERA wires
  - Diffusion rate measurements after collimation (in SPS, RHIC, etc…)
  - JLab end station profile monitor
  - SNS Beam in gap (longitudinal halo)
- **Effects of halo growth**
  - Loss monitors
  - Thermocouples near ISIS target and planned for SNS
  - Background measurements in detectors

Emittance Measurement

Typically, slit and collector →

- Beginning: Input for simulations to
- End: result after growth



Another type of emittance measurement:
Scanning pinhole emittance scanner for Heavy ion fusion studies

- Motivation: after beams are merged and neutralized, bulk of beam must hit fusion target
- Space charge dominated beam "neutralized" by selecting small beamlets with pinhole
- Complete 4-D emittance measurement of converging beam
  - Correlations are measured
  - Very time consuming

Ultimate: 6-D phase phase measurement

Profile measurement techniques (1 of 4)

The early days

- Foil activation
- Photographic film
- Glass plates
- Plastic sheets

- Physical analysis completed offline
- Still of use for calibration
- SNS will analyze activation profile of target

Profile measurement techniques (2 of 4)

Invasive targets

Traditional:

- Harps/multiwires
- Stepping wires
- Flying wires
- Aperture-collector
  - Like emittance scanners

More Exotic:

- Liquid wires
- Sodium curtains

Profile measurement techniques (3 of 4)

Not-so-invasive targets

- Residual gas ionization
  - Connolly, et. al.
- Gas fluorescence
  - Requires excited states with fast decay time
- Beam fluorescence
- Laser beam probes
  - Compton scattering, stripping
- Particle beam probes
  - i.e. measure deflection of electron beam probe
- Wall currents
  - i.e. quadrupole moment detection with electrodes

Profile measurement techniques (4 of 4)

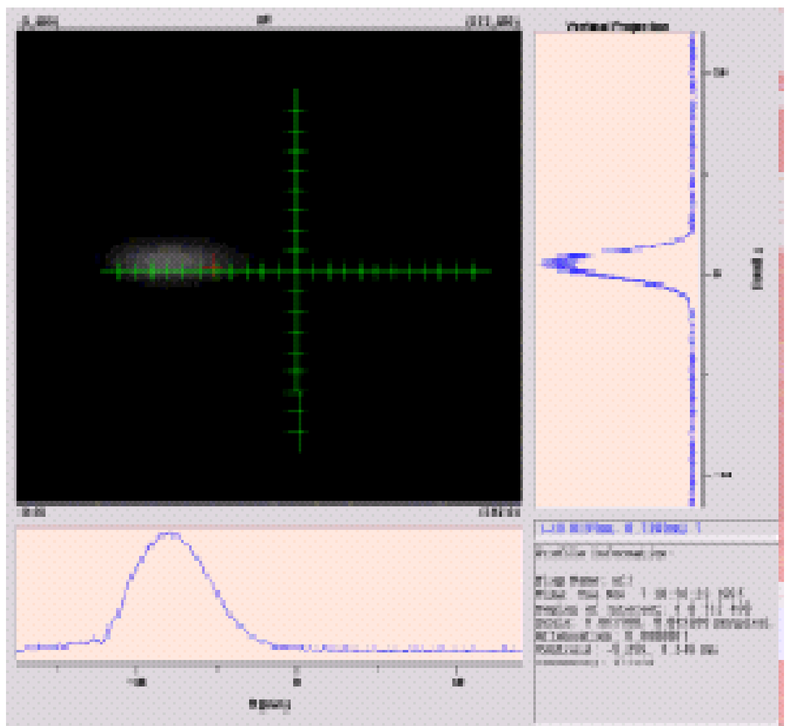
2D Imaging (both invasive and non-invasive)

- Phosphor screens
- Optical transition radiation
- Array detector in beam
  - Even a CCD has been deployed in beam (short lived)
- IR imaging
- Synchrotron radiation

Typical 2D imaging devices
Phosphor, OTR, Synch. Light, …

Particle Beam	Converter Screens	Radiation	Imaging Optics	Radiation Pattern	Readout Device	Video Signal	Digitizer
Electron Proton / Ions	Phosphor OTR Magnets	Light X-Ray	Lens Mirror Diffractive	Direct Indirect	CCD camera Streak Cam Many others	Analog Digital	

phosphor screen display for the RHIC Injection Line:



2D Imaging devices Specifications

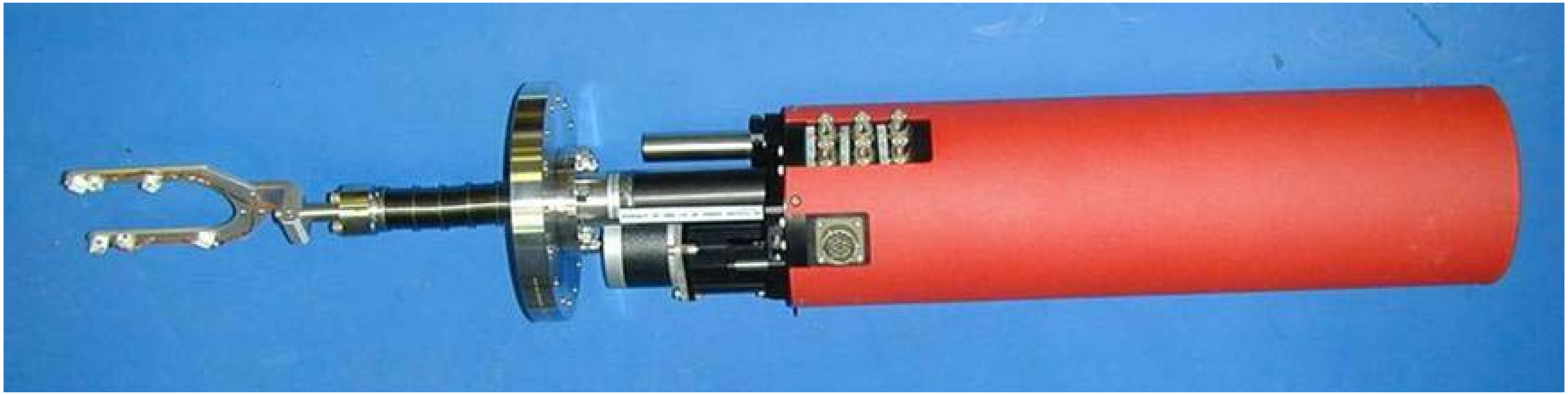
- Usually not specified to measure halo
  - Potential is there
  - But saturation, dynamic range of electronics,…
- Rapid acquisition
- X, Y correlation

Typical tolerance Budget for an imaging profile monitor (APS Flag):

Source of Error	**Size Tolerance**
Screen defects	1.0%
Optics defects	1.0%
Resolution	2.0%
Calibration	1.4%
Statistics	2.0%
Total	**3.5%**

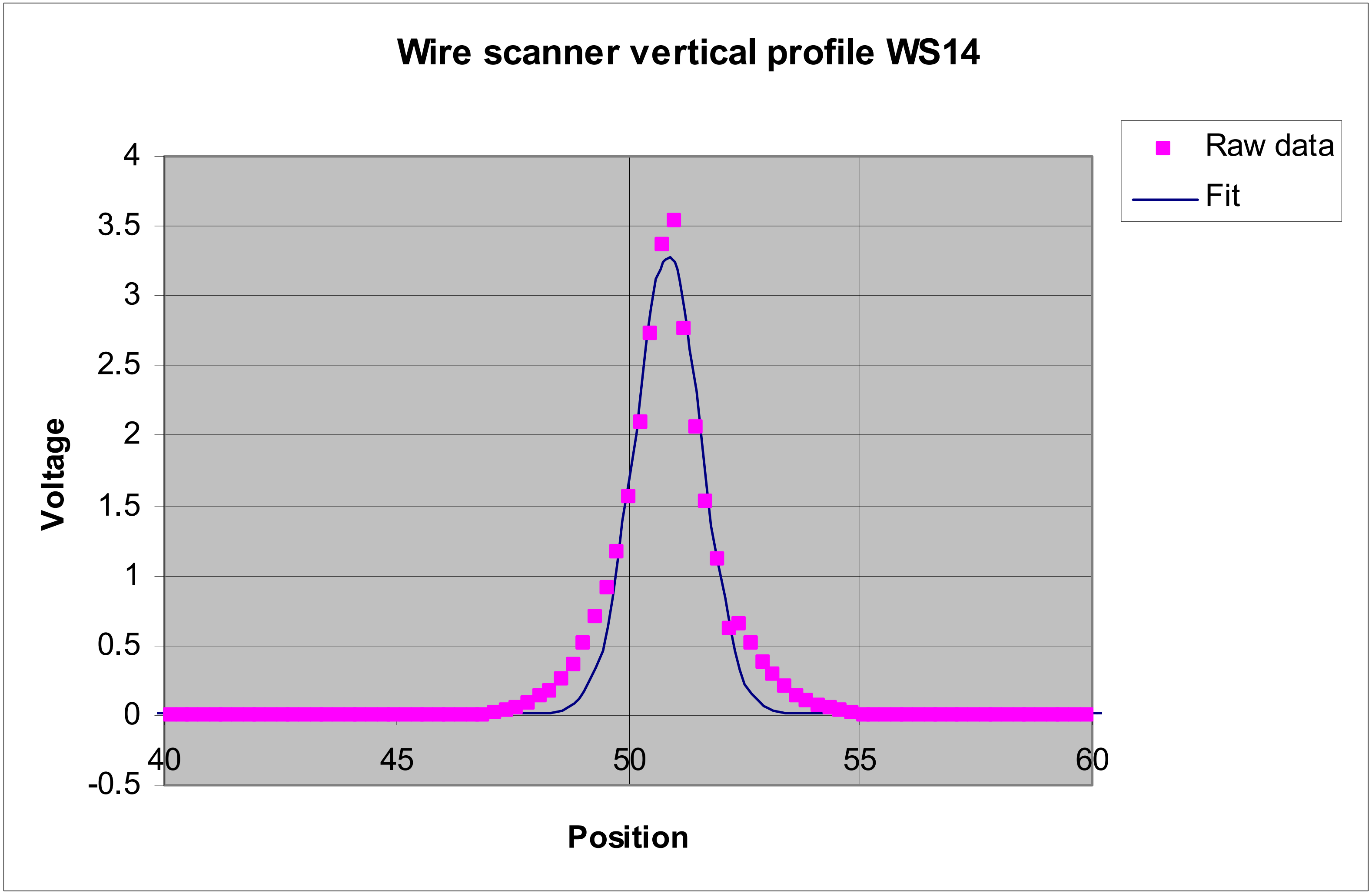
Typical Wire Scanner

- SNS carbon wire scanners:
  - Spec: 10% accuracy, 5% resolution of RMS beam width
  - Direct measurement of secondary emission current
  - In Ring: option of detecting particle shower with fast PMT-based loss monitors



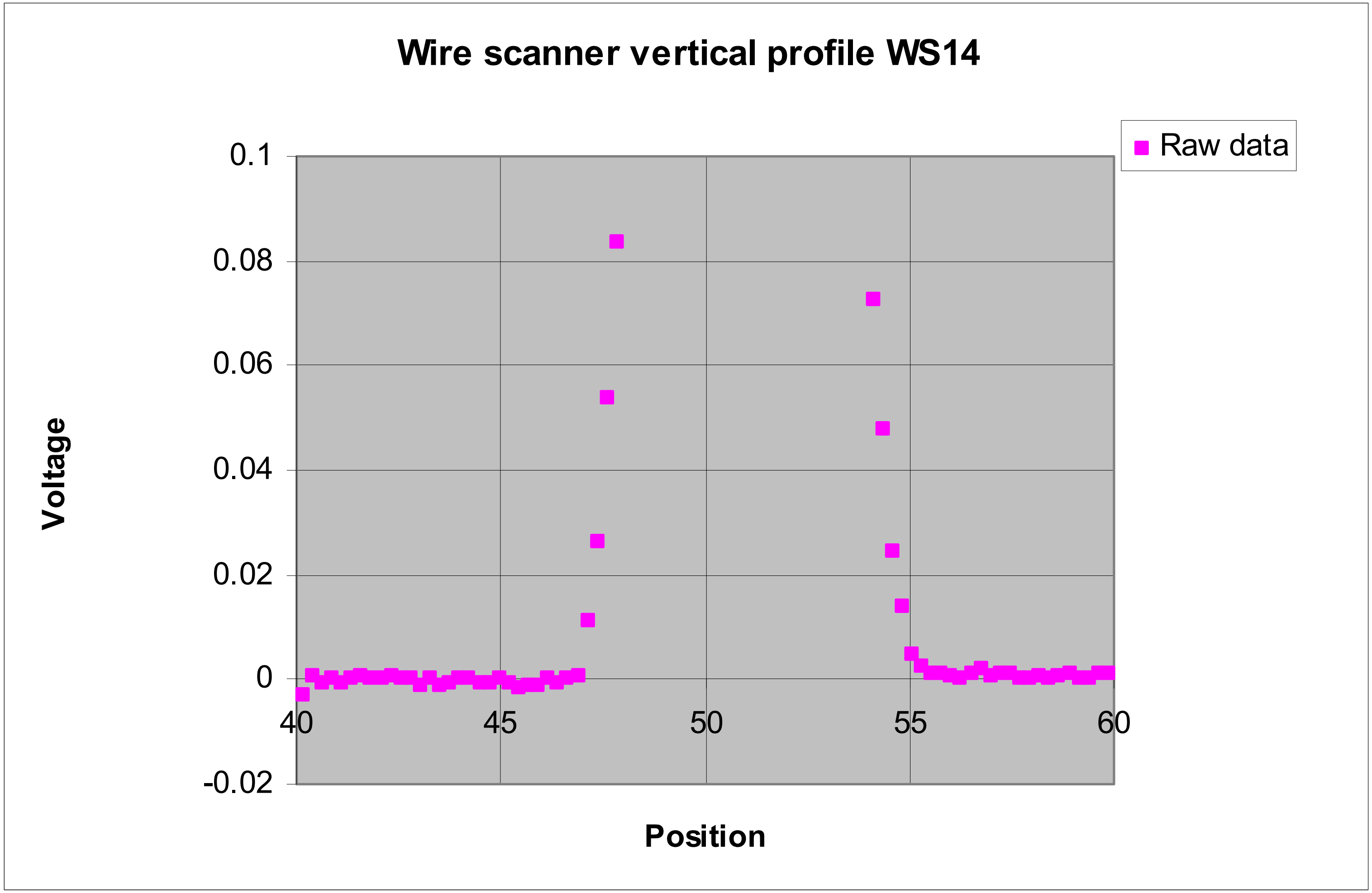
SNS Carbon wire scanner
Measurement of secondary emission current

- Raw data shows larger tail than Gaussian profile



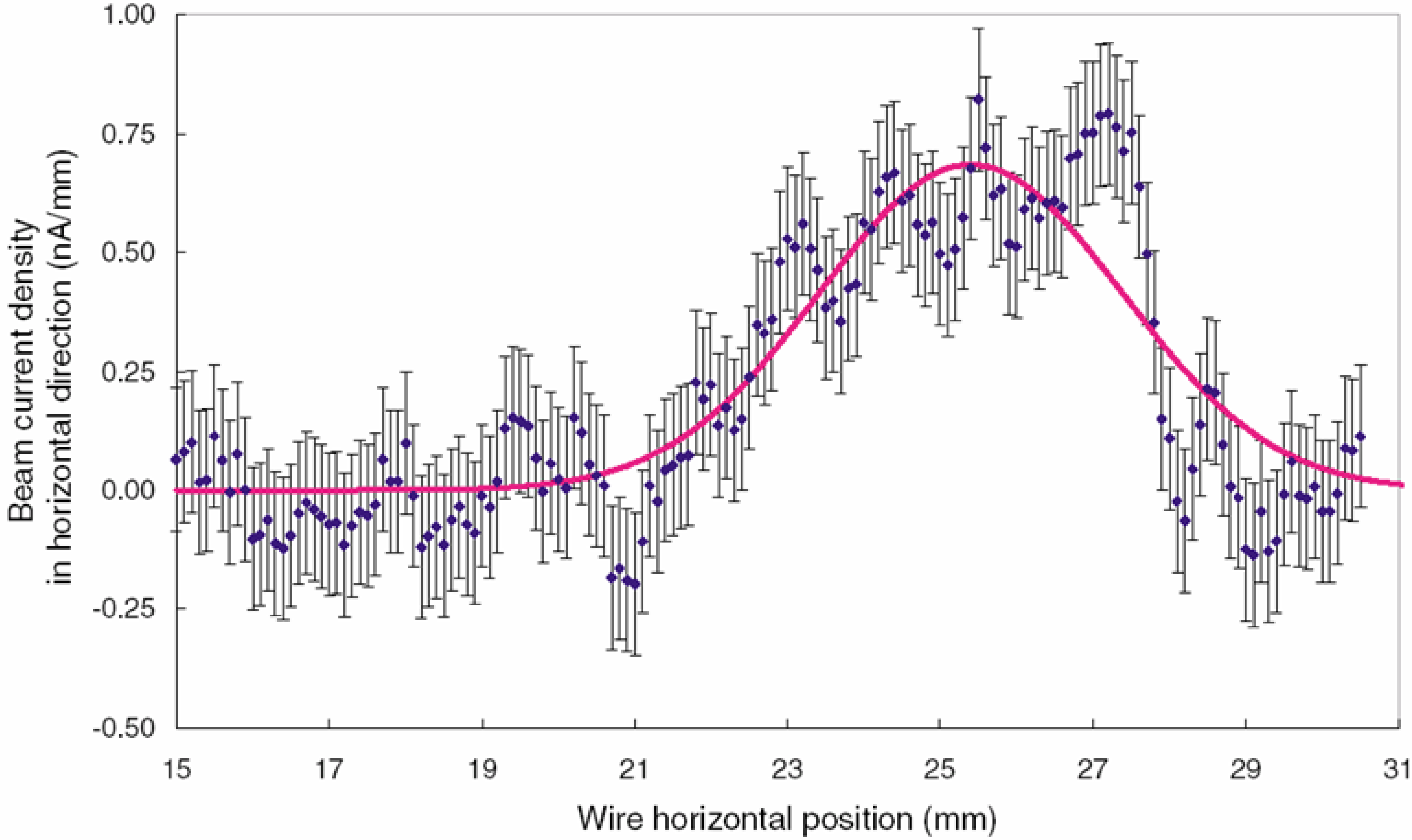
SNS Carbon wire scanner
Measurement of secondary emission current

- One minute for full scan (each point averaged over 8 beam pulses)
- Noise level less than 0.002 Volts compared to 3.5 Volt peak (>10^-3)



Vibrating wire scanner (VBS)
Problem: wire heating. Solution: wire heating

- Measures effect of wire temperature – other heating mechanisms near high current beam?
- Demonstrated in < 1nA/mm beam 1D projected current density
- S/N in this experiment dominated by electromagnetic interference,



Specification for measuring beam tails

- LHC transverse profile monitor specification:
  - detect densities of 10^-3 (for single bunches), to 10^4 (for PS batches) of the maximum of the distribution.
  - there is no demand to extend the dynamic range up to the peak density of the bunch/beam
  - The processes occurring in the tails are not expected to vary rapidly and the integration time of the measurement can be made long (seconds or minutes)

Traditional profile monitors
Improving dynamic range

Current mode → Counting mode

Increasing linear dynamic range

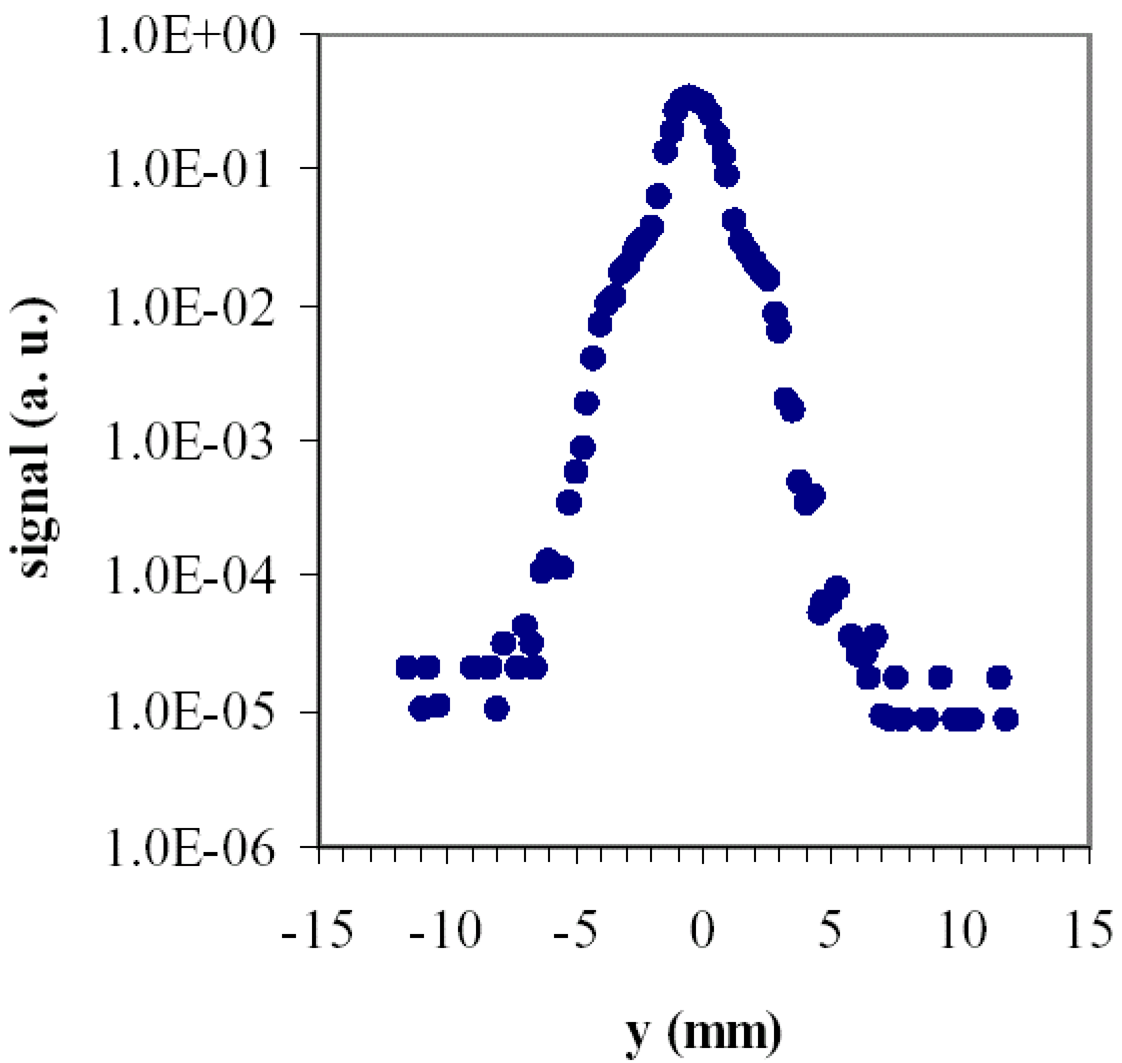
1 Wire → multiple targets

Increasing signal for tail measurements

- Analog front ends & digitizers are improving (Integral nonlinearity of data acquisition systems better than 10^-5), but counting experiments still have the edge
- Remaining issues involve knowledge and control of beam/target interaction region
  - Systematic effects
  - Background in some applications (coincidence techniques can help)
  - Stability for lengthy measurements

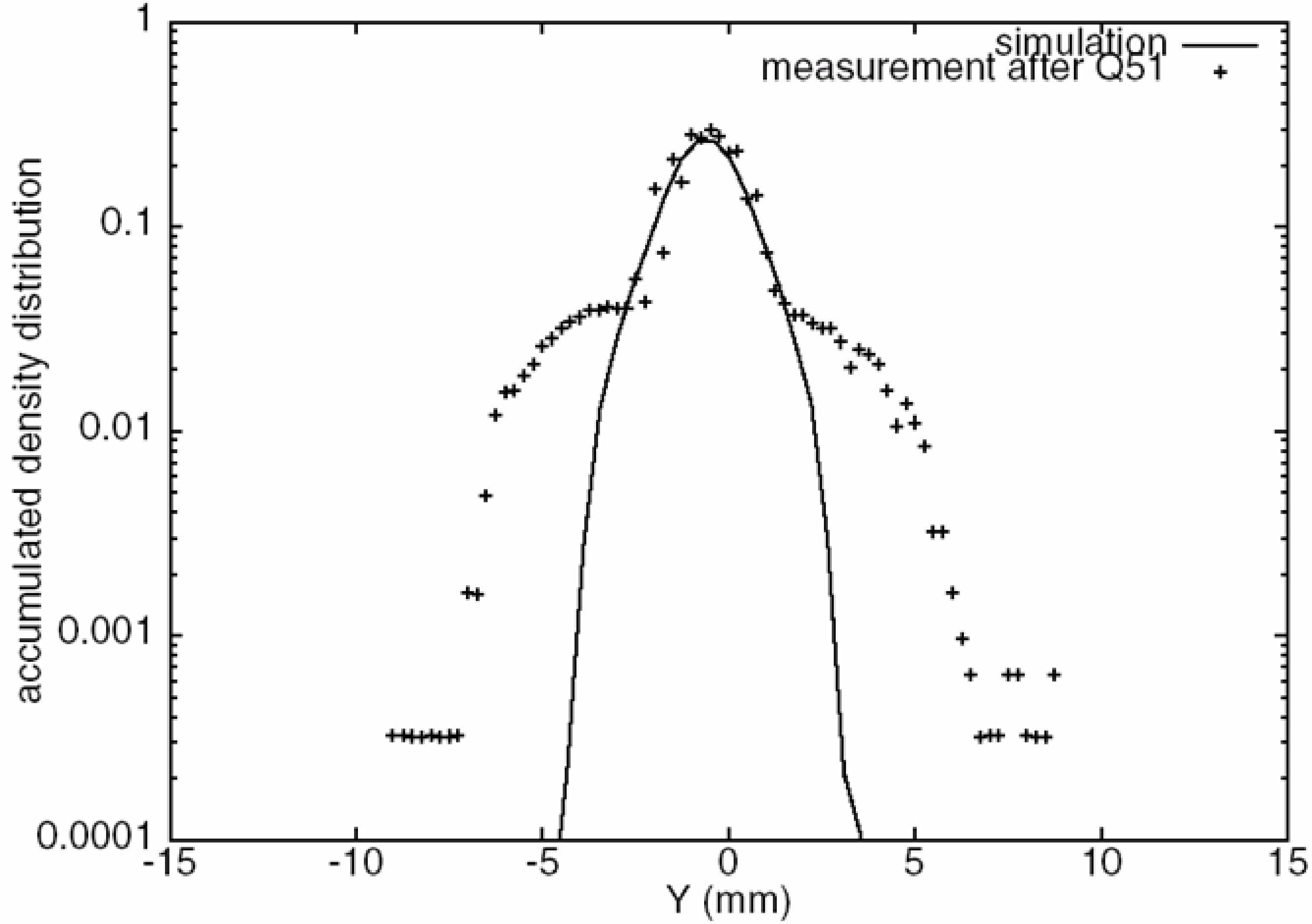
LEDA measurements

- Motivation: pure study of halo evolution
- Data from wire and scraper are combined into composite profile
- Update from Gilpatrick



LEDA measurements
Recent analysis

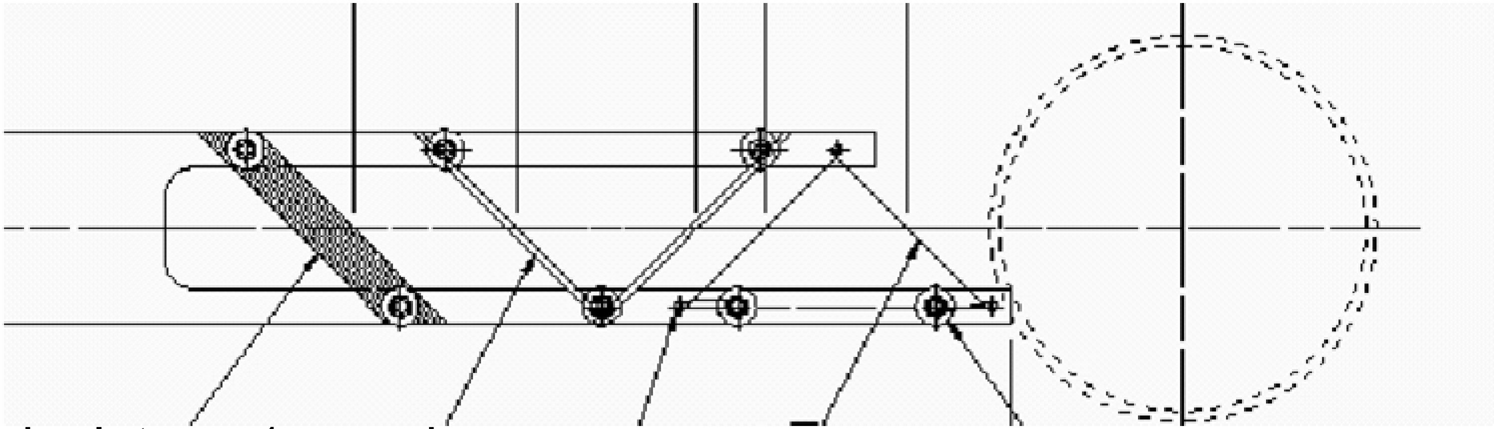
- For bunched beam, initial 6-D phase space measurement may be required as input into simulation
- More from Wangler



Halo measurements at JLab

- Motivation for measurement: Halo hitting target frame can cause event rate comparable to rate from target itself
- Upstream of CEBAF Large Acceptance Spectrometer

- Combined data from 25 micron and 1 mm Fe wires, and 1mm thick Fe plate, similar to LEDA data analysis

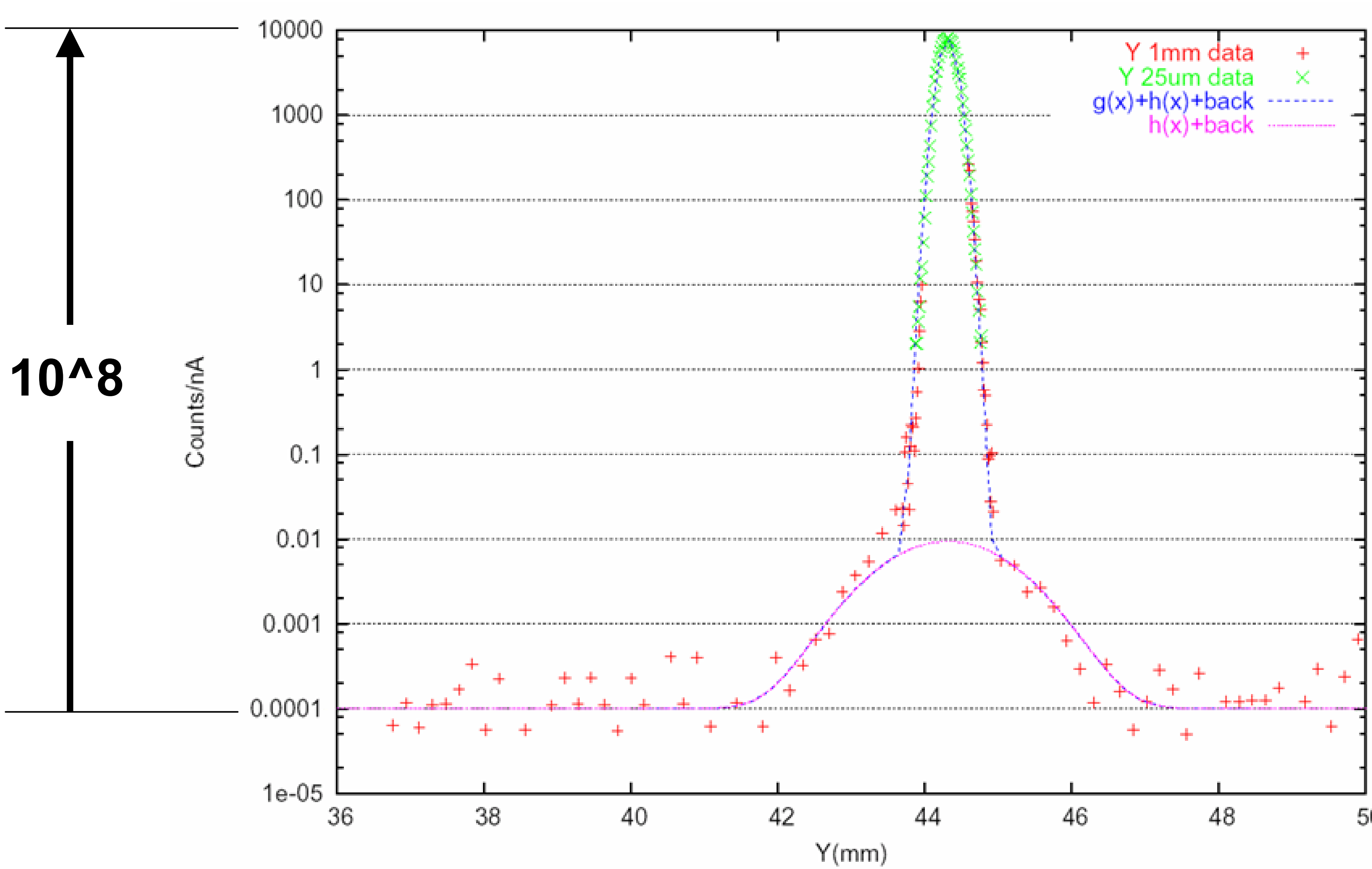


1mm thick plate 1mm wire

1mm thick plate

Halo measurements Upstream of CEBAF Large Acceptance Spectrometer

- Combined data from 25 micron and 1 mm Fe wires



Challenge: Building trust in profile measurements

- Sparse distribution
  - Within one machine: Unlike BPMs, cross-correlation within a machine is not typical
  - Across various machines: exotic techniques are usually not available at multiple machines with similar beam (compare w/ button BPMs & switched electrode electronics in light sources)
- Steps forward
  - Continue dedicated experiments (ref. reports from Snowmass 01, ICFA Diagnostics 02)
  - Identify commonality in existing devices/applications – combine data/experience

In Closing, Some General Goals for Workshop

- Fundamental and operational definitions of halo
- Requirements for diagnostics

- Define current state of the art
- Define goals
- Identify promising technologies and techniques
- Identify promising experiments

- Foster continued collaboration in all the above